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SOLAR ARRAY FROM THE SPACE PLASMA

by

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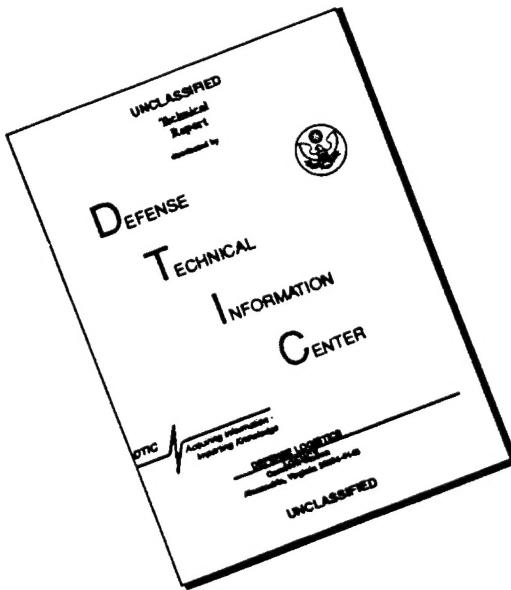
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THE CURRENT COLLECTION BY HIGH VOLTAGE
SOLAR ARRAY FROM THE SPACE PLASMA

Gu Shifen Shi Ligin Song Li Tian Baoning

ABSTRACT

This article presents a type of theoretical statistical model which is capable of conveniently calculating high voltage solar array (HVSA) current collections given rise to by space plasma. Through analysis of physical processes, it is believed that HVSA power consumption caused by space plasma should not be ignored with regard to HVSA design.

Key Words Space plasma High voltage solar array Current collection

I. INTRODUCTION

Following along with unceasing increases in the scale of spacecraft and enlargements of missions, the requirements on electric power sources have also constantly increased. Future space stations will need electric power sources as high as 200kw.

In order to lighten structural weight, reduce Ohmic losses as well as supplying electrical current and interactive influences between geomagnetic fields, it is then necessary to increase operating electrical voltages associated with solar cell arrays. Solar arrays operating at 100V and above are called high voltage solar cell arrays, or simply HVSA.

A good number of such things as spacecraft, manned space shuttles, and space stations associated with military objectives all operate in low earth orbit (LEO) at altitudes of 200-250km. The natural plasma environment in the interval in question is composed of high density ionosphere plasma ($\geq 10^9 \text{ el} \cdot \text{m}^{-3}$) as well as low energy ($< 100 \text{ keV}$) subsidence plasma. In this type of environment, the interactions which are given rise to by HVSA operations are very complicated. One of the important reactions among these is HVSA current collection--also called current leakage. High electrical conductivity associated with plasma causes exposed conductor sections on HVSA to form parallel connection circuits with it, thereby creating electrical power source current leakage and loss of active power. Due to the fact that, under conditions where electron temperatures and plasma temperatures are close to the same, electron mobilities will be much higher than ions, the effects in question will, therefore, be displayed as HVSA electron current collection with regard to the surrounding plasma.

HVSA current collection research is primarily being carried out in several of the U.S. NASA's research center surface simulation laboratories. There have also been two iterations of space flight tests (PIX-1,2). However, they were subject to limitations from equipment dimensions, as well as fringe effects, differences in plasma sources, inaccuracies in the parameters, and so on. Not only are the interaction results not completely consistent. Differences between simulations carried out and actual space situations are also very great. Differences in results obtained in the area of theoretical calculations are wide. Therefore, understanding basic plasma collection processes in solar arrays still requires a considerable amount of work [1,2].

We have carried out theoretical research with regard to HVSA current collection questions and present one type of theoretical model.

II. TWO DIMENSIONAL COMPUTER SIMULATION MODEL

We make use of mixed, iterative numerical value programs associated with fixed surface conductor plate two dimensional Poisson-Vlasov problems. Option is made for the use of

$\phi = e\phi/T_e$ (eV), $J_e = j_e/j_{e0}$ and so on to carry out nondimensional operations. T_e is the ambient electron temperature. j_{e0} is ambient electrothermal random current density.

With regard to different numerical value calculations, selection is made of current densities associated with locations closest to impact direction surfaces ($0.005r_0$) and obtained from various respective calculations, setting up a statistical approximation relationship of the form:

$$\bar{J}_e = a + b\phi^x. \quad (1)$$

Making use of data obtained by program operations $\Phi: 10, 52, 100, 150$ and corresponding $\bar{J}_e : 0.38, 0.52, 0.64, 0.70, 4$ equations (1) are constructed. Sets two by two compose 5 equation sets. Respectively solving for a , b , and x values, selection is made of the closest parameter set $a=0.2$, $b=0.046$, $x=0.49$, thereby giving the current collection model constructed by the computer simulations in question:

$$I_e = j_e A_e = A_e j_{e0} \bar{J}_e = A_e j_{e0} \left(0.2 + 0.046 \left| \frac{e\phi}{T_e} \right|^{0.49} \right). \quad (2)$$

HVSA power losses $\Delta p(W)$ given rise to by current collection are

$$\Delta p = I_e \phi = A_+ j_{e0} \left(0.2 + 0.046 \left| \frac{e\phi}{T(\text{eV})} \right|^{0.46} \right) \phi, \quad (3)$$

In the equations, A_+ is the electron collection area. Based on conditions where the net plasma current on HVSA is zero:

$$I_e^i = j_e \cdot A_+ = I_i^i = j_i \cdot A_-, \quad (4)$$

It is possible to derive, under the influence of LEO impact surface ions having drift speeds of $M = \left(\frac{m_i v_i^2}{kT_i} \right)^{1/2}$

and under the conditions $n_e = n_i$, $T_e = T_i$, the existence of

$$\frac{A_+}{A_-} = \frac{j_i}{j_e} \approx RAM \left(\frac{m_i}{m_e} \right)^{1/2}, \quad (5)$$

$$RAM = \exp(-M^2) + \sqrt{\pi} (1 + \text{erf}M). \quad (6)$$

In particular, under conditions where $v_s = 7 \text{ km} \cdot \text{s}^{-1}$ and the ions are oxygen ions, $M \approx 6.4$. $\text{RAM} \approx 23$. At this time, $A+/A- = 0.134$. $A+ + A- \approx A_p$ (array area), and one has

$$A_+ \approx 0.12 A_p, \quad (7)$$

$$j_{e0} = e n_e \left(\frac{k T_e}{2 \pi m_e} \right)^{1/2} = 2.7 \times 10^{-14} n_e [T_e (\text{eV})]^{1/2}. \quad (8)$$

Obviously, it is only necessary to specify environmental plasma conditions n_e and T_e as well as high voltage solar array parameters A_p and ϕ , and it is then possible to combine the use of equations (2), (3), (7), and (8) to solve for the HVSA collection currents our model gives as well as the electrical power source losses these lead to.

III. USABILITY OF MODELS

In order to precisely specify the usability of models we have set up, it is necessary to take them and carry out comparisons with other models. In order to make the comparisons and discuss HVSA current collection power losses given rise to by space plasma, we select for use the typical parameter values that follow: $n_e = n_i = 10^{12} \cdot \text{m}^{-3}$, $T_e = T_i = 0.2 \text{ eV}$. Ions are oxygen ions. These are typical ionosphere plasma characteristic values associated with 300-400km altitude areas. $P = 30 \text{ kW}$. $A_p = 300 \text{ m}^2$.

These are typical values associated with the needs for solar cell array powers in the first phase of future space stations. Array operating voltages are selected as 100, 150, 200, 250, 300, 400, 500, and 600V to carry out calculations. At this time--utilizing equation (7)--it gives $A+ = 36 \text{ m}^2$. Making use of equation (8), it gives $j_{e0} = 1.2 \times 10^{-2} A \cdot \text{m}^{-2}$. By the C-L binary third order square rule [3]

$$j = \frac{4\sigma_0}{q} \left(\frac{2e}{m}\right)^{1/2} \frac{1}{B_i^2} \phi^{1/2}, \quad (9)$$

Then, using equation (4)'s $j_e \cdot A^+ = j_i \cdot A^-$, it is easy to make use of A^+/A^- relationships to calculate out

$$\phi_+/\phi_- \approx 0.125 \text{ 或 } \phi_+ \approx 0.11\phi_- \quad (10)$$

After one has such relationships as those above, we are then able to give current collection forms for the data of Viswanathan and others [2] based on surface laboratories:

$$\phi_+ \leq 100V, I_e = j_{e0} A_p (1.25 \times 10^{-3}) \left(1 + \frac{e\phi_+}{T_e(\text{eV})}\right); \quad (11a)$$

$$\phi_+ > 100V, I_e = j_{e0} A_p (0.25) \left(1 + \frac{e(\phi_+ - 100)}{T_e(\text{eV})}\right); \quad (11b)$$

$$\phi_- \leq 0V, I_e = j_{i0} A_p (1.25 \times 10^{-3}) \left(1 + \frac{e|\phi_-|}{T_i(\text{eV})}\right). \quad (11c)$$

With regard to the carrying out of calculations under the conditions we give, as far as equation (11a) is concerned, $\phi j_e 0 A_p (1.25 \times 10^{-3}) = 4.5 \times 10^{-3} A$. The results are shown in Table 1.

Table 1 Viswanathan Et Al Current Collection Model Calculation Results

| $\phi(V)$ | 100 | 150 | 200 | 250 | 300 | 400 | 500 | 600 |
|------------------|------|------|-------|-------|-------|-------|-------|-------|
| $\phi_+(V)$ | 11.0 | 16.5 | 22.0 | 27.5 | 33.0 | 44.0 | 55.0 | 66.0 |
| $e\phi_+/T_e$ | 55 | 82.5 | 110.0 | 137.5 | 165.0 | 220.0 | 275.0 | 330.0 |
| $I_e(A)$ | 0.25 | 0.37 | 0.50 | 0.62 | 0.74 | 0.99 | 1.24 | 1.48 |
| $\Delta P(W)$ | 25 | 56 | 100 | 155 | 222 | 396 | 620 | 891 |
| $\Delta P/P(\%)$ | 0.09 | 0.19 | 0.33 | 0.52 | 0.74 | 1.32 | 2.07 | 2.97 |

Making use of our model, calculations are as shown in Table 2.

Table 2 Two Dimensional Computer Simulation Statistical Model Results

| $\phi(V)$ | 100 | 150 | 200 | 250 | 300 | 400 | 500 | 600 |
|------------------|------|------|------|------|------|------|------|------|
| $I_e(A)$ | 0.50 | 0.60 | 0.68 | 0.74 | 0.81 | 0.91 | 1.01 | 1.09 |
| $\Delta P(W)$ | 50 | 90 | 135 | 185 | 243 | 364 | 505 | 654 |
| $\Delta P/P(\%)$ | 0.17 | 0.30 | 0.45 | 0.62 | 0.81 | 1.21 | 1.68 | 2.18 |

Taking Table 1 and Table 2 and carrying out comparisons, it is not difficult to see that results are very close between our model and models associated with comprehensive processing of data based on surface laboratories. In particular, when array operating voltages are 200V or above, differences between the two are not great. That is nothing else than to say that our model is usable. In terms of utilization, our model is more convenient than the models of Viswanathan and others. It saves on excessively numerous operations such as calculating ϕ_+ , and the results obtained are just as usable. /45

IV. RESULTS, DISCUSSION, AND CONCLUSIONS

Due to actual HVSA structures themselves, materials, electrical generation effects, as well as distinctions used in experiments, and, on the other hand, actual space environments having to be much more complicated than surface simulations, there are not only changes in perturbations from movements in the natural environment. There are also, moreover, environmental additives (pollution) caused to be in space systems. Therefore, surface laboratories which already exist and secondary space flight laboratory results are inadequate to form a completely reliable basis for high voltage solar cell array design.

We believe that, no matter whether it is laboratory data models which already exist or theoretical models like the one we have given, they are capable, in all cases, of being on the low side with regard to calculations associated with HVSA current collection causing power losses--as given rise to by space plasma. The main factors are two. (1) As far as current leakages given rise to by HVSA electrical discharges are concerned, at the present time, they are still difficult to estimate and have not been calculated into various models which already exist. (2) The influences of multilayered dielectrics associated with solar cells have not been designed into models. With regard to conductors carrying positives that they will collect coming from secondarily radiated electrons associated with the vicinity of dielectrics, it is obvious that, when there is high secondary electron radiation, there will necessarily be an increase in current collection associated with mutual conductor metal connection plates [4]. This is the cause for the appearance of "snapover" phenomena in current collection. Snapover phenomena are phenomena associated with abrupt increases in current collection when HVSA are placed in a certain positive voltage. The voltage in question is a complex function associated with space plasma environments, HVSA structures, materials, as well as their movement configurations. At the present time, there is still no clear relationship. It is a problem which should be studied.

Electric power source losses brought on by current collection associated with space plasma HVSA are, in the final analysis, not an important factor in problems. At the present time, in international terms, points of view are still not unanimous. On the basis of the three reasons below, we believe that it is an important factor which needs to be considered in HVSA designs.

(1) When arrays are in the darkness of night at a location in question, at that time, power sources are cut off, and, in conjunction with that, cool. Once they again enter into the illumination of the sun, the cooled arrays will need to produce 2 fold the rated voltage values until the temperature reaches a normal value. Despite the fact that this process occurs within just a few minutes, this type of voltage multiplication effect cannot, however, be ignored. For example, when the original design voltage was 200V, plasma caused power losses were only 0.45%. By contrast, when the 2 fold voltage is 400V, losses increase to 1.21%.

(2) Model calculation values which have already been pointed out above will possibly be lower than reality. Moreover, as far as space plasma environments following solar activity are concerned, geomagnetic activity sees complicated changes.

(3) With regard to HVSA in long term LEO movements, in order to make the final phase still match up with predicted power requirements, the power capabilities which need to be produced in initial operating periods will be much greater. Viswanathan and others have pointed out that an array design that normally requires 70kW must, at the outset, be able to supply 200kW. This, of course, makes array areas enlarge a great deal and makes power losses caused by current collection even larger.

Summarizing the above, we arrive at the following conclusions.

(1) The theoretical model which we have given is simple and usable.

(2) Electric power source losses caused by HVSA currents given rise to by space plasma should be considered in HVSA designs.

(3) HVSA current collection processes given rise to by space plasma still need further in depth research. This should involve power losses caused by current leakage from electrical discharges as well as the effects of current collection around dielectrics with regard to mutual metal connector plates.

(4) As far as space plasma current collection associated with high voltage system is concerned, it not only has significance with regard to HVSA. It has, moreover, application significance with regard to plasma switches and mooring systems.